(4)

ON INSUFFICIENCY OF THE POWER OF CONVERGENCE.

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[Translated under the author's direction by W. T. Law, M.D., F.R.C.S.]

For the proper accomplishment of binocular vision two conditions are necessary:—1. The image of the object must be simultaneously formed upon the fovea centralis of each eye. 2. This image must be distinct.

The first condition is fulfilled when the visual lines cross at the point of fixation. This depends upon the *motor apparatus*, whose function is to give to the eyes the convergence required by the distance of the object. The realisation of the second condition concerns the *optical apparatus* of the eyes.

Of these two elements of binocular vision the former is by far the more important. Without proper direction of the eyes such vision is absolutely impossible, while it may very often be effected satisfactorily to the individual, in spite of imperfection of the retinal images. Moreover, it is very easy to correct optical errors by glasses, while it is much more difficult to remedy a defect of movement or direction in the eyes. Alterations in the latter are very frequent. They often give rise to an asthenopia, in the treatment of which there is yet much to be desired, for we are still far from sufficiently understanding the functions of the motor apparatus in relation to binocular vision, or the means of correcting their anomalies. For a long time I have studied this important question, and would here venture to give a resumé of the results at which I have at present arrived. Should these, however, fail to solve the numerous questions connected with the subject, I hope they may at least help to point out the way of conducting the investigation.

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For simplicity's sake I have called by the term *convergence** the faculty of simultaneously directing the two

Fig. 1.

* Landolt. Refraction and Accommodation, p. 185—194. Young, J. Pentland, Edinburgh, 1886.

eyes to the object of fixation, whether the distance be finite, infinite, or even beyond infinity. The most natural method of measuring the convergence is by means of a fixed object placed in the median line (M M', Fig. 1.) In this way the *angle of convergence* is always the same for each eye. This angle necessarily affords the measure of the convergence effort put forth by each eye. In distant vision, the two eyes (O and O') having a parallel direction, this angle is nil. It increases in proportion as the object fixed is brought nearer. It may be said then that the size of the angle of convergence is in *inverse* proportion to the distance between either eye and the fixed object in the median line.* If the object be at C at the distance O C=C, the angle of convergence J O C can be expressed by $C = \frac{1}{C}$. In measuring this distance C by the aid of the metre we obtain for the convergence required in binocular fixation an expression identical with that of the refraction necessary for distinct vision of the same object. Thus, supposing an object be situated at a distance of one metre from each eye there must be for both eyes $\frac{1}{1m} = 1$ dioptry of positive refraction and $\frac{1}{1m} = 1$ unit of positive convergence. This unit is called, after Nagel, to whom we are indebted for this principle of measurement, the *metre angle.*† If the object is placed at $\frac{1}{3}$ metre from each eye $\frac{1}{1m/3} = 3$ D and 3 *m. a.* are required, and so on.

The *amplitude* of convergence is obviously contained between the maximum and minimum of the convergence which an individual is capable of exerting.

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* In reality the inverse of the distance does not give the *angle* of convergence but its sine; for our purpose, however, we may conveniently substitute one for the other.

† An expression analogous with *metre lens*, which Nagel has proposed for the dioptry. The *absolute* value of the metre angle depends upon the distance which separates the centres of rotation of the eyeballs from each other. For instance, if this, the base line, is 58 mm. in length, the metre angle = $1°39'39''$. If 64 mm. the metre angle will = $1°50'$ and so on.—Nagel in Graefe-Saemisch, Handbuch VI., p. 478.

The *maximum* of convergence is inversely as the distance of the nearest point, *punctum proximum of convergence*, which can be fixed binocularly. If P be the distance which separates this point from each eye, the maximum of convergence is $= \frac{1}{P}$. In measuring the distance P by means of the metre we can replace this fraction by the value p metre angles.

The *minimum of convergence*, upon the same principle, is inversely proportional to the distance which separates each eye from the *furthest* point, which can be fixed binocularly. If R be the distance of this *punctum remotum of convergence*, the minimum of convergence will be $\frac{1}{R} = r\,m.a.$ If this point be situated at a *finite* distance, the minimum of convergence is *positive*, and can be determined in the same manner as the maximum, as I shall explain hereafter. But this only happens in pathological cases. Under normal conditions the lines of fixation can at least be directed parallel with each other. The minimum of convergence in such a case is equal to zero, because the punctum remotum is situated at infinity and $r = \frac{1}{\infty} = O$. Most normal eyes, however, can *diverge* more or less. The minimum of convergence is then *negative*. It is always inversely proportional to the distance of the punctum remotum, only as the lines of fixation diverge this point is not situated in front of the head but behind it—*R* (Fig. 1), where the lines of fixation, prolonged backwards, meet.

The amplitude of convergence (a) is represented by the difference between the maximum and the minimum of this function: $a = p - r$. In normal cases I have found on an average that the minimum of convergence is about -1 *m. a.*; the maximum 9·5 *m. a.*; and the amplitude of convergence therefore 10·5 *m. a.*

When the minimum of convergence is *negative*, its amount is measured by the strongest abducting prism, which can be overcome in distant vision. Nothing is easier than to express in metre angles the effect of a prism. The exact calculations have been given

by Nagel, and, also, in my own work.* In practice it is sufficiently accurate to divide the number of the prism by 7 to obtain, in metre angles, the deflection required to overcome it. (The distance between the centres of rotation of the two eyeballs in this case is taken as between 58 and 64 mm.) A prism of 14° held horizontally before *one* eye, requires from *each* a rotation of $\frac{14}{7} = 2$ *m.a.*, *adduction* if the edge of the prism is turned inwards, *abduction* if outwards. Anyone who in distant vision can overcome a prism of 5° has a minimum of convergence $- r = \frac{5}{7} = \cdot 71$ *m. a.*

When we desire to ascertain whether a patient's power of converging is sufficient or not, p should be taken as the starting point of our investigation. But in order to determine whether asthenopia is due to insufficiency of this function we must know, first of all, how much convergence the individual requires for his work. This important point is not easily ascertained, and, strange to say, seems to have been entirely overlooked. For vision at a distance of $\frac{1^m}{3}$, 3 *m. a.* of convergence are essential. If, however, an individual's utmost capacity for convergence does not exceed this amount; in other words, if his punctum proximum of convergence is situated at $\frac{1^m}{3}$, continuous work at that distance will be impossible. For sustained effort a reserve of convergence power is necessary to replace what is expended in work. Only when we have gauged this reserve fund of strength can we tell with certainty whether the patient has motor-asthenopia or not, and if so, by how many metre angles he fails to reach the required standard. It is evident that this reserve power cannot be an absolute quantity (for instance, 2 *m. a.*) in all cases, but that it must represent a tolerably constant proportion of the total amount. My experience seems to show that this reserve force must be at least twice as great as the convergence employed. Thus in order to work at a distance of one metre, that is to

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* Landolt, l. c., p. 194.

say, with 1 *m. a.*, I must have 2 *m. a.* in reserve, making a total of 3 *m. a.* Again, to continuously converge to $\frac{1^m}{4}$, $3 \times 4 = 12$ *m. a.* are wanted.

In order to decide whether asthenopia results from want of power of converging, I first learn the distance at which the patient requires to work, and then place his refraction in the most favourable condition for this purpose. Suppose the working distance to be $\frac{1^m}{3}$, I ascertain if he possesses $3 \times 3 = 9$ *m. a.* of positive convergence. If he has 10 or 11 *m. a.*, there is no fear of muscular asthenopia. 9 *m. a.* would be just on the border line, but if p is less than 9 *m. a.*, for instance only 7, the patient has at least $9 - 7 = 2$ *m. a.* too little.

Now comes the question, how can we compensate this deficiency of convergence power, and cure the asthenopia? First of all, *prismatic glasses* occur to our minds. Their necessary strength can be calculated from my previous remarks. One metre angle is equivalent to a prism of 7° for one eye, or 3·5° for both. Therefore, assuming as in our example a deficiency of 2 metre angles, it would be requisite to place prisms of 7° before both eyes. For well-known reasons, however, prisms of this strength cannot be employed in practice. For spectacles we are not able to exceed prisms of 5°, which will only correct a failure of 1·4 *m. a.*

When, therefore, the insufficiency exceeds 1·5 *m. a.*, we should avoid tiring the patient with optical appliances, and if by rest and hygienic measures no improvement results, we must resort to *surgery*. We have to take into consideration the question of performing either tenotomy of the external recti,* advancement of the internal,† or a combination of the two operations. It is highly interesting to observe the effect of these procedures upon the range of convergence and its composition (as regards its maximum and minimum elements). Before entering

* For details of method of operation I adopt, see *loc. cit.*, p. 402.
† *Loc. cit.*, p. 406.

upon this, however, it is time we should more closely consider the nature of the disease, for upon this depends the result of our operations.

Everyone acquainted with muscular or motor asthenopia must be aware that there exist two distinct forms of the affection. Von Graefe has already shown this, and A. Graefe has further developed the subject in his valuable work on "Motilitaetsstörungen." Krenchel's interesting essay, too, on the same subject is generally known; the most accurate of all, however, are the views of my friend Horner, of Zürich.

Of the two recognised varieties of motor-asthenopia, one may be termed *peripheral*, the other *central*. The

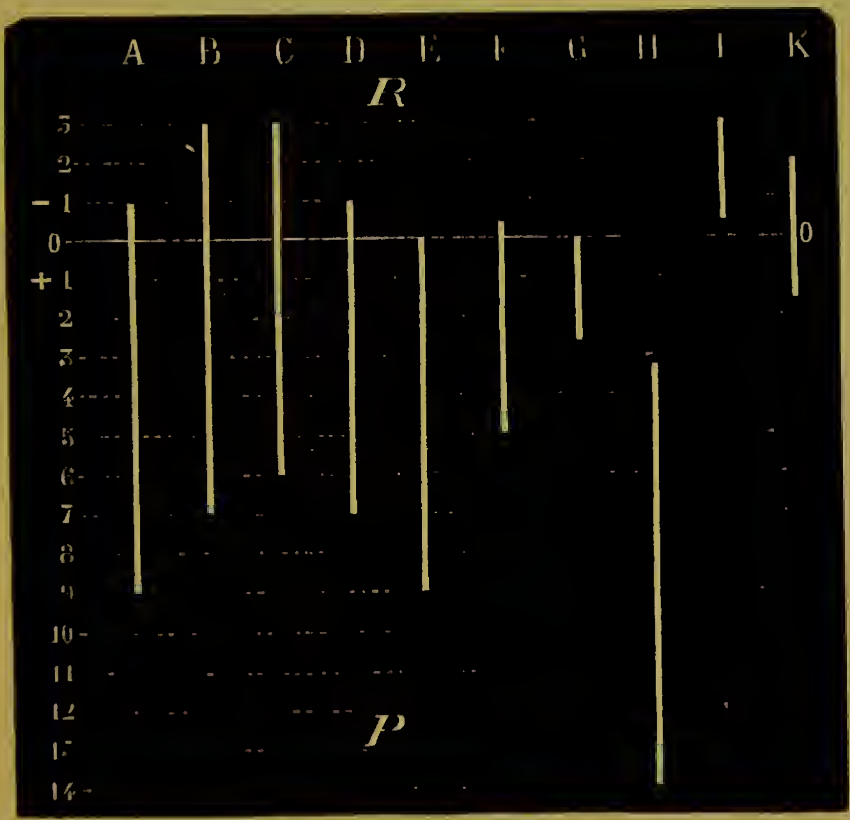

Fig. 2.

first can be called muscular asthenopia in the true sense of the words, being dependent upon the absolute or

relative power of the adductor muscles, upon their insertions. The second variety has a central cause, and arises from a disturbance of innervation of the muscles of convergence, or in the power of fusion. We need not be surprised to frequently find that the associated movements are normal in such cases, for, without doubt, the function of convergence is controlled by a special nervous centre. My experience goes to show, although I cannot yet assert it with absolute certainty, that these two forms are characterised by the mode in which the range of convergence is affected. This may occur in various ways, as is shown in the foregoing schema.* In this diagram the range of convergence is represented by the vertical lines; the full horizontal line indicating zero. Those parts of the vertical lines above the horizontal stand for the negative part of the convergence; those beneath for the positive portion. The dotted lines and the figures indicate metre angles. At A is shown the normal condition in which the positive convergence (p) is about nine times as great as the negative (– r.) It may happen that the entire range of convergence is removed to the negative side. In this case – r becomes greater, and p proportionately less, as at B. Such a condition may arise simply from excessive strength of the abductors, without either muscular insufficiency or disturbance of innervation of the internal recti, tenotomy of one, or, if necessary, both of the externi, gives very good results in these cases.

CASE 1.—Strong man, æt. thirty.

$$\left.\begin{array}{lll}\text{Left.} & \text{Myopia} & = 6\text{ D} \\ \text{Right.} & \text{,,} & = 7\text{ D}\end{array}\right\} \text{Astig. 1·25 D in both eyes.}$$

Acuteness of vision both sides normal.

Muscular asthenopia.

$$\left.\begin{array}{l}p = 7 \\ r = -3\end{array}\right\} a = 10\,m.a. \quad \text{(Fig. 3, left line.)}$$

* Landolt, l. c., p. 502.

Three days after *tenotomy* of one external rectus I found

$$\left.\begin{array}{l} p = \ \ 12 \\ r = -1 \end{array}\right\} a = 13 \ m.\ a.$$

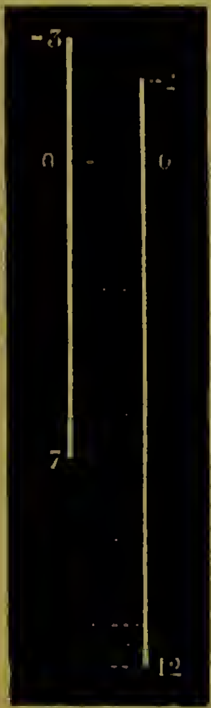

Fig. 3.

The asthenopia entirely disappeared, and after more than a year it was found that

$$\left.\begin{array}{l} p = \ \ 12 \\ r = -2 \end{array}\right\} a = 14 \ m.\ a.\ \text{(Fig. 3, right line.)}$$

Favourable results may thus be obtained from tenotomy even in cases where a decided diminution in the range of convergence is present, provided it be not excessive, and that the positive part only be affected (Fig. 2, C). But here advancement of the internal rectus appears also to answer very well.

Case 2.—Post office employé, æt. fifty.

$$\begin{array}{l} L : H = \ \cdot 75\ D;\ \ V = \cdot 5 - \cdot 6. \\ R : H = \ \cdot 75\ D;\ \ V = \cdot 7 \end{array}$$

Amplitude of accommodation = 2·5 D

Uses convex 2·5 D.

Muscular asthenopia.

$$\left.\begin{array}{l} p = 7 \\ r = -1 \end{array}\right\} a = 8\ m.\ a.$$

Tenotomy of the right external rectus; no suture. Immediately after the operation

$$\begin{array}{l} p = \text{about } 15\ m.\ a. \\ r = \text{,,} \ -{\cdot}5\ m.\ a. \end{array}$$

Ten weeks after the operation

$$\left.\begin{array}{l} p = 10 \\ r = -1{\cdot}25 \end{array}\right\} a = 11{\cdot}25\ m.\ a.$$

CASE 3.—Teacher, aged between twenty and thirty. Very good constitution.

L and R : H = ·5; V = 1.

FIG. 4.

Accommodation normal. Very pronounced muscular asthenopia.

$$\left.\begin{array}{l} p = 3{\cdot}5\ m.\ a. \\ r = -2{\cdot}5\ m.\ a. \end{array}\right\} a = 6\ m.\ a. \quad \text{(Fig. 4, left line.)}$$

Free *tenotomy* of the right external rectus; no suture. Both eyes bandaged. The following day

$$\left.\begin{array}{l} p = 10\ m.a. \\ r = -1{\cdot}25\ m.a. \end{array}\right\}\ a = 11{\cdot}25\ m.a.$$

Ordinary exercise of convergence. Eighteen days after the operation

$$\left.\begin{array}{l} p = 15 \\ r = -2 \end{array}\right\} a = 17\ m.a.\ \text{(Fig. 4, right line.)}$$

FIG. 5.

Fields of fixation:

Left.	Right.
Temporal, 50°.	Temporal, 45°.
Nasal, 45°.	Nasal, 50°.

Asthenopia cured.

CASE 4.—Boy, æt. thirteen.

L and R myopia = 1·25 D.

V = ·7 and 1 respectively.

Muscular asthenopia.

$$\left.\begin{array}{l} p = 3{\cdot}25 \\ r = -2{\cdot}3 \end{array}\right\} a = 5{\cdot}5\ m.\ a.$$ (Fig. 5, left line.)

Advancement of one internal rectus. After more than a year

$$\left.\begin{array}{l} p = \text{more than } 20 \\ r = \quad -2 \end{array}\right\} a = 22\ m.\ a.$$ (at least).

(Fig. 5, right line.)

CASE 5.—Woman, æt. thirty-five.

L : hypermetropia = ·75 D ; V = ·7.

R : ditto = ·5 D ; V = ·8 to ·9.

Muscular asthenopia.

$$\left.\begin{array}{l} p = 7 \\ r = -1 \end{array}\right\} a = 8\ m.\ a.$$

Advancement of one internal rectus. Six days after we found

$$\left.\begin{array}{l} p = 14 \\ r = -1{\cdot}5 \end{array}\right\} a = 15{\cdot}5\ m.\ a.$$

The asthenopia was cured. In this case, before the operation, I found both fields of fixation somewhat contracted, especially at the inner side.

When the positive part of the convergence range is shortened, the negative being of normal extent, tenotomy may, as I have already stated, be advantageously practised, but if − r be diminished to ·5 *m. a.* or less, advancement of the tendon is undoubtedly preferable.

When both positive and negative parts of the amplitude of convergence are considerably shortened, as shown at F and G of the schema (Fig. 2), we usually have to deal with the second or *neuropathic* form of insufficiency, which is characterised by a noticeable diminution of the range of convergence.

Similar conditions are met with, it is true, in high myopes, in whom, in consequence of enlargement of the eyeball, the muscles being unduly stretched, lose their elasticity, and are also impeded in action owing to the divergent position of the globes. In such patients, the range of convergence may be reduced to less than 3 *m. a.*,

without - r having much increased. Any operation for cases like these gives most unsatisfactory results, as I have pointed out elsewhere.* Instead of increasing the range of movement it lessens it still more.

CASE 6.—Young man, æt. twenty-five.

Myopia = 18 D and 20 D.

Eyeballs considerably enlarged, divergent, and restricted in movement.

$$\left.\begin{array}{l} p = 1{\cdot}5 \\ r = -2 \end{array}\right\} a = 3{\cdot}5\ m.\ a.$$

Tenotomy of one external rectus. In a week or two the condition was—

$$\left.\begin{array}{l} p = 7 \\ r = +4 \end{array}\right\} a = 3\ m.\ a.$$

Thus the patient had still insufficient convergence for near work, while he had excess, *i.e.*, convergent strabismus with homonymous diplopia, for distance; besides which the range of movement was actually less than before the operation. Later on, after a moderate tenotomy of one internus, he lost his strabismus, and r became = O, but the punctum proximum receded till p = 2·5 *m. a.* only. The amplitude of convergence was thus reduced to 2·5 *m. a.*

Such cases can easily be distinguished from the neurasthenic class, however. This latter, while exhibiting considerable lessening of the range of convergence, presents no peculiar abnormality in either the form of the eyeball, the refraction, or the associated movements. The treatment of this class of cases is extremely difficult, for where we often have to deal with a deficiency of convergence of 6 *m. a.* and more, prisms are out of the question, while muscular advancement, the operation commonly to be chosen on account of the small extent of the negative r, is attended with only temporary benefit. Exercise of the affected organs, as A. von Graefe properly observes, would only increase the weakness of the affected muscles by tiring them. We shall gain

* *Loc. cit.*, p. 512.

† A. von Graefe in Archiv. of Ophth. viii., 2, p. 345, 1862.

most from ocular hygiene and attention to the general health, though I would not entirely exclude, in suitable cases, all operative aid or prisms. The two following cases are characteristic examples of the neuropathic form of motor asthenopia.

CASE 7.—A young nun.

$$\left.\begin{array}{l} \text{L : myopia} = 2{\cdot}25 \text{ D} \\ \text{R : \quad do.} = 2{\cdot}75 \text{ D} \end{array}\right\} \text{V} = 1.$$

Asthenopia of high degree. When the eyes were quiescent there was divergent strabismus of 5°.

p did not exceed 1 *m. a.*

In the course of five months I successively advanced both interni, and tenotomised both externi; the immediate effect was, on each occasion, very good, and for some time there was even considerable convergent strabismus with homonymous diplopia, which, after a time, passed off, as did also, for a while, the asthenopia; nevertheless, at this moment,

$$\left.\begin{array}{l} \text{p is only} = 4 \\ \text{r} \qquad\quad = -2 \end{array}\right\} \text{a} = 6 \textit{ m. a.}$$

Both apparent divergent strabismus and asthenopia still persist to a certain extent. It would be impossible to find a better instance of remarkable reduction of the power of convergence or fusion. The insertion of the externi has visibly receded, while the interni have become attached close to the corneal margin. The operations performed would have sufficed to cure the highest degree of external squint, but, notwithstanding this, the eyes can only converge to a distance of ¼ metre, while they have regained their former condition of divergence. The field of fixation is almost normal in the horizontal plane, though, perhaps, slightly increased internally. Still more instructive is the following:—

CASE 8.—A young teacher who observes and answers very accurately. There is general weakness of the muscular system.

L : myopia = 1·5 D; V = 1.
R : do. = 2 D; V = ·8

Motor asthenopia which prevents him working for more than four hours daily. Fields of fixation somewhat limited in every direction.

$$\left.\begin{array}{l} \text{p} = 4{\cdot}5 \\ \text{r} = -{\cdot}5 \end{array}\right\} \text{a} = 5 \textit{ m. a.}$$

Advancement of one rectus internus. Four days after the operation

$$p = \text{more than } 20 \; m.\,a.$$
$$r = + 1{\cdot}5 \; m.\,a.$$

There was, therefore, over-correction.* During the next few days positive convergence for distance even increased, whereas for near vision it diminished. But, after a time, the former disappeared entirely, the patient was no longer troubled with diplopia, and he could work easily without abducting glasses. In three months' time, however, the old asthenopic trouble reappeared. He then again took to prismatic glasses, which gave him temporary relief, but eventually he came back again to me, and examination frequently repeated showed—

$$\left.\begin{array}{l} p = \;\;4 \\ r = -{\cdot}5 \end{array}\right\} a = 4{\cdot}5 \; m.\,a.$$

The patient's condition is thus the same as before the operation.

Let me quote another striking example of neurasthenic muscular asthenopia in

CASE 9.—Young girl, æt. 20.

L : M 2·75 D; V=1.
R : M 2·75 D; V=1.

With the ophthalmoscope the actual myopia proved to be = 2·5 D.

Muscular asthenopia.

Tenotomy of the right external rectus. Immediately after the operation

$$\left.\begin{array}{l} p = 15 \\ r = +\,2{\cdot}5 \end{array}\right\} a = 12{\cdot}5 \; m.\,a.$$

Conjunctival suture so that r was reduced to 0 *m. a.* The next day

$$\left.\begin{array}{l} p = 15 \\ r = \;\;0 \end{array}\right\} a = 15 \; m.\,a.$$

Suture removed.

Patient was able to work, free from asthenopic troubles, for a

* The state of affairs here is shown at II in diagram 2, where the entire range of convergence is situated in the positive region. This is especially met with in cases of paralytic convergent strabismus. I (Fig. 2) illustrates the opposite condition, occurring in divergent squint, where convergence is entirely confined to the negative region.

time, but eleven months later she returned with the same complaint. The amplitude of convergence was as follows :—

$$\left.\begin{array}{l} p = 3 \\ r = -\cdot 5 \end{array}\right\} a = 3\cdot 5 \; m.a.$$

A treatment consisting of hygienic strengthening measures was then ordered, but, notwithstanding, the amplitude of convergence continued to diminish, and consequently the asthenopia increased. Nine months after the examination cited, twenty months after the first operation, we found

$$\left.\begin{array}{l} p = 1\cdot 75 \\ r = -1\cdot 75 \end{array}\right\} a = 3\cdot 5 \; m.a. \quad \text{(Fig. 6, first line.)}$$

Fields of fixation :

Left and right nasal 49°.
temporal 50°.

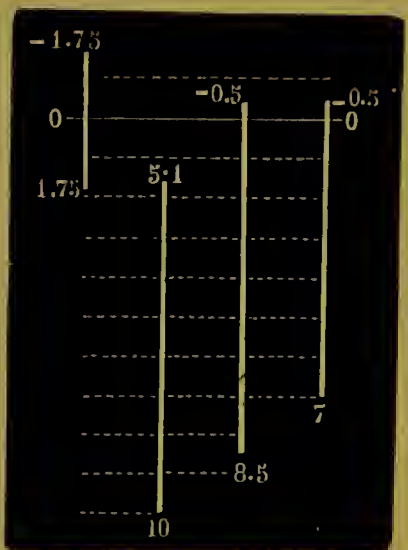

Fig. 6.

Advancement with a slight resection of the internal rectus of the right eye was then performed. Both eyes were bandaged for five days, when the sutures were removed and the eye operated on alone bandaged. Two days after the operation there was

$$\left.\begin{array}{l} p = 10 \\ r = +1\cdot 5 \end{array}\right\} a = 8\cdot 5 \; m.a. \quad \text{(Fig. 6, second line.)}$$

Ten days after the operation

$$\left.\begin{array}{l} p = 8\cdot 5 \\ r = -0\cdot 5 \end{array}\right\} a = 9 \; m.a. \quad \text{(Fig. 6, third line.)}$$

We had therefore gained $9 - 3{\cdot}5 = 5{\cdot}5$ *m. a.* of amplitude of convergence, and increased the positive part from $1{\cdot}75$ to $8{\cdot}5$ *m. a.*

This amount would have sufficed for near work, at least, with the help of weak prismatic glasses.

But the power of convergence still shows a tendency to decrease, so that four days ago, that is to say, three weeks after the advancement, I found

$$\left.\begin{array}{l} p = 7 \\ r = -{\cdot}5 \end{array}\right\} a = 7{\cdot}5\,m.a. \text{ (Fig. 6, fourth line.)}$$

It is highly important to note that this patient belongs to a family subject to neurotic troubles. Her mother was anæmic and very "nervous" from the age of twelve to fourteen. She had convulsive attacks affecting the upper extremities, which necessitated confinement to bed. A great aunt suffers from hysterical crises and contortions. The patient herself developed neurotic symptoms at the age of fourteen. She grew impatient in temper, had typical globus hystericus daily, lasting about four hours, from the seventeenth to the twentieth year, fits of laughing and crying, palpitations, and, a fortnight ago, anæsthesia of the legs succeeded an emotional outburst. At the same time, walking was very difficult. The latter symptoms have spontaneously and suddenly disappeared. The left (non-operated on) eye she says is becoming sometimes very painful under the influence of emotion, without presenting any objective symptom.

I am not unmindful of the fact that not only may absolute insufficiency of convergence or accommodation cause asthenopia, but that the affection may arise in cases where either function, taken by itself, being normal, there occurs inco-ordination in their combined action. In other words, with a normal *absolute* range of convergence and accommodation the *relative* range of these functions may be affected.

This happens, for instance, in young hypermetropes in whom insufficient relative range of accommodation leads to excess of convergence—squint, in fact. This, of course, is not insufficiency of convergence, but rather

its opposite. The treatment of this relative and frequently also absolute insufficiency of accommodation is well understood.

On the other hand, it is possible, especially with myopes, that the correct convergence calls forth an excess of accommodation. A myope requires to bring into play less accommodation in proportion to his ametropia than the emmetrope; but it happens that he cannot sufficiently separate the two functions from

FIG. 7.

one another, and that with a given degree of convergence he associates too great an amount of accommodation. From the point of view of the accommodation such cases could be regarded as examples of insufficiency of convergence, or rather of the positive part of the relative

range of convergence.* If, however, the absolute convergence is normal, it appears to me incorrect to speak in such cases of insufficiency of convergence. As to treatment, I should decline to operate, especially since for distance we generally find even the relative convergence normal. Cases like these are more correctly considered as instances of excess of the positive part of the relative range of accommodation. They may be called and treated as spasm.

The diagnosis of these different cases is easily established by use of my dynamometer.

The Ophthalmodynamometer.

This little instrument consists of a cylinder (C, fig. 7) which can be fixed to any candle of ordinary size. It possesses (1) a vertical slit of about ·3 mm. in breadth, (2) a vertical line consisting of a series of fine openings, (3) a circular aperture of about 1 mm. diameter. The openings are all covered with ground glass, and when the candle is lighted they form shining objects, thrown into sharp contrast with the blackened exterior of the cylinder. Under each opening is placed a hook, to which can be attached the end of a measuring tape constructed to wind up by a spring in the ordinary way. This tape is divided into centimetres one side, beginning from its free end, and on the other side into the corresponding value in metre angles or dioptries as the case may be. Thus the numbers, 16, 15, 14, &c., in the diagram (Fig. 7) stand for centimetres; 20 and 18 indicate metre angles or dioptries. 11 cm. would thus correspond with 9 D or 9 *m. a.*, 20 metre angles with 5 cm., and so on.

To ascertain the maximum of convergence, the tape being partly withdrawn, its case is held at the outer margin of the orbit, so that the aperture through which the tape issues is on a level with the point of rotation of the eyeball. The patient is then told to look at the

* Landolt. Loc. cit., p. 283.

vertical line upon the cylinder, and the instrument is gradually brought nearer in the median line, until he says the line appears double (crossed diplopia). The measure is then removed, and the distance of the punctum proximum read off on one side of the tape, and the maximum of convergence upon the other. We must, of course, make sure that the patient fixes the object with both eyes, and it is therefore desirable to watch his movements so as to see that he really follows its approach. For persons who are unable to decide readily whether they see double or not, we may use coloured glass at first, which can be afterwards dispensed with.

As muscles, especially those of the eye, do not contract with mathematical precision, it is indispensable that we should repeat the examination several times in succession, and upon different occasions. I, myself, never operate until I have ascertained the degree of insufficiency accurately by making repeated examinations and at different times.

Lastly, it is advisable to begin the approximation of the light from a distance considerably further from the patient than his punctum proximum, and not to commence by placing the light close to the nose, because, while in the former case it is easy for him to increase his convergence gradually as the light approaches, in the latter he generally overcomes the commencing crossed diplopia only when his punctum proximum is considerably passed.

It sometimes happens, however, that persons can converge up to the point of the nose, to a shorter distance, in fact, than the object can be brought within, and that their punctum proximum of convergence is so close that we cannot ascertain the precise maximum within one or two metre angles. These cases have, however, no practical interest, for when the power of convergence exceeds 16 *m. a.*, it is, at any rate, not insufficient. For experimental purposes, we can adopt

means similar to those employed where the accommodation near point is unusually close, for, just as in the latter instance, by employing concave lenses the punctum proximum can be put further away artificially, so where convergence is concerned the near point may be removed to a greater distance by adducting prisms. The value of the prisms in metre angles being added, of course, to the so-found p.

The *minimum* of convergence, if positive, can also be estimated with the dynamometer, and will be found to be in inverse ratio to the greatest distance at which the bright line can be perceived as a single object. Should homonymous diplopia begin at only two metres distance so that r is less than half metre angle, the flame alone may be used, as the aperture forms too fine an object, but this very seldom happens.

To define the range of accommodation, the fine openings of the apparatus are used. These are gradually brought nearer the patient, till they appear indistinct, and the result is read off on the tape in dioptries instead of metre angles, and the maximum of refraction in the place of maximum of convergence. When a person is emmetropic, the maximum of refraction of which he is capable is equal to the range of accommodation.

The same line of bright points may be used in investigating the relations existing between the converging or motor and the accommodative or optical apparatus of the eyes. When convergence and accommodation harmonise the patient will be able to distinctly see the row of luminous points as such. If convergence be at fault, the line will appear double, the diplopia being crossed if there be insufficiency, or homonymous if excess. Should there be any failure in the optical adaptation, especially error of accommodation, the points will appear blurred. The kind and amount of error—that is to say, the differential diagnosis between excess and deficiency of accommodation, can then be estimated by trial lenses in the usual way.

The circular aperture of the dynamometer is useful in the analysis of all possible kinds of derangements of motility which are accompanied by diplopia.

The case also contains a little frame (18×25 mm.) with a handle in which threads, hairs, small objects, such as printed letters, or a diaphragm with fine holes, can be placed to define the range of accommodation.*

* The little instrument can be obtained from Pickard and Curry, 195, Gt. Portland St., W.; Roulot, Optician, 58, Quai des Orfèvres, Paris; and Meyrowitz Bros., 295, Fourth Avenue, New York.